Low Cost Molded Packaging for Optical Data Links

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Abstract - In order to lower the cost of optical data link packaging, a new technology has been developed which integrates optical and electrical components in a single, sealed, transfer molded package. This technology utilizes leadframes for low cost and mass handling. Overmolding is used for package sealing and optical port alignment. A unique process, two step transfer molding, allows for internal shielding, intermediate IC testing, ease of assembly and IC package sealing. An injection molded outer housing is used for connector insertion and external shielding (through the use of conductive plastics).

The first application of this technology is a high performance optical transceiver package for the growing FDDI market (125 MB/s). With a duplex MIC connector, this package conforms to an industry standard outline and pinout. The optical transceiver easily meets full FDDI specifications. The design integrates an LED, PIN, transmitter IC, receiver IC and two capacitors in a single, overmolded package. The final assembly sequence was conceived using the latest Design For Simplicity (DFS) principles. This paper describes the design concept and prototype model performance results.

INTRODUCTION

Market projections indicate that the sales of optical data links will continue to grow significantly over the next few years. This growth in the market has been sparked by significant reductions in price -- allowing the technology to be extended to a wider range of applications in local area networks, fiber to the desk and fiber to the home programs. To keep pace, the manufacturing technology for optical data links must migrate to one that can produce high volumes (hundreds of thousands) at a very low cost.

One aspect of optical data link technology that is ripe with opportunities for cost reduction is packaging. First generation optical data links such as AT&T's ODL® 125 Transmitters & Receivers use die cast metal housings that are individually assembled with the optics and electronics [1]. There is a large number of fixturing, clamping and adhesive curing steps. Many of these operations must be conducted serially on one ODL at a time. Other optical data links such as AT&T's ODL 125 Series II go one step further by packaging the integrated circuits (IC) in conventional DIP packages. The electronics and optics are then individually assembled into an injection molded plastic frames [2]

The package we describe in this paper is a high performance optical transceiver for the growing Fiber Distributed Data Interface (FDDI) market (125 MB/s). With a duplex MIC connector, this package conforms to an industry standard outline and pinout. The design integrates active optical components (LED & PIN), transmitter and receiver ICs, and several passive components in a single, overmolded package. The fully assembled package is shown in figure 1.

BACKGROUND

The intent of this project was to develop an ODL package that was similar in design and manufacture to conventional molded plastic packaging for silicon integrated circuits. This technology [3] is used to package more than 85% of the 30 Billion ICs manufactured in the world each year. It offers high efficiency assembly of the components on leadframes using automated and consistent operations such as wire bonding, die placement and die attach. Devices are handled in low cost leadframe strips with 5-10 devices per strip. The process has high productivity in that millions of ICs can be produced on a manufacturing line per month. In addition, AT&T is a leader in IC packaging technology [4] and has all of the necessary capital and human resources to realize this ambitious program. Finally, the package obtained is very high in quality. The minimal use of manual operations and the extremely high yield of die attach, wire bonding, and molding operations means that manufacturing defects are held to an absolute minimum. Also, the molding compounds and the process technology of molding have advanced to the point that the reliability of molded plastic packages rivals that of far more expensive ceramic packages.

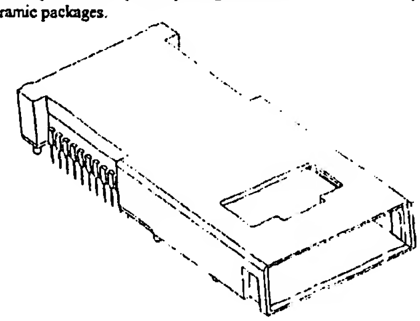

Figure 1. Low Cost FDDI Transceiver

PACKAGE DESIGN OBJECTIVES

The goal of the design was to develop an optical data link technology which is low cost, high performance, wave solderable and aqueous rinsable. In addition, the design would be reviewed and amended according to Design for Manufacturing (DFM) and Design for Simplicity (DFS) principles to minimize assembly costs and potential production problems. The design is intended for high volume production using low cost, mature packaging technologies such as leadframe assembly and transfer molding.

There were several design criteria that were applied. The package should be pin and outline compatible with the present generation FDDI transceiver (1402U) -- a 2x11 industry standard pinout. This mandated a remetalization of the integrated circuits so that the bonding pads were located where they could be accessed by the inner leads of the leadframe. The package should also utilize the existing 1402U Optical Sub-Assembly (OSA) and "TO" header. These OSAs will be placed in a machined or injection molded barrel for later overmolding as shown in figure 2. In addition, there should be a way to incorporate electromagnetic interference (EMI) shielding into the package; preferably as a feature of the leadframe rather than as an add-on part.

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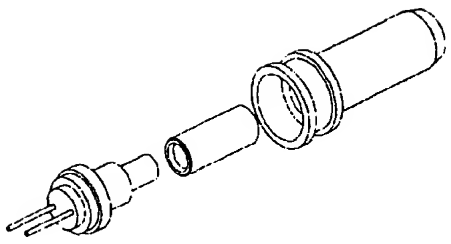

Figure 2. Optical Sub-Assembly Inserted in Barrel (optical port)

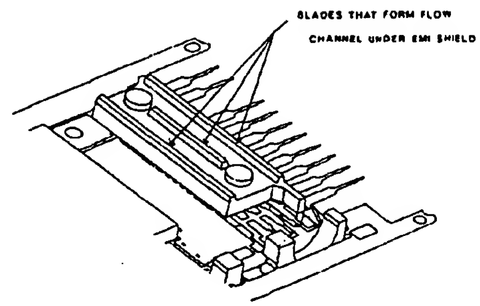

Figure 3. Molded Receiver DIP package with EMI shield spacers

Another major constraint was the need to test ICs after molding so that OSAs would only be mounted at sites where there were known good devices. The need to test ICs after assembly and prior to OSA attachment prompted a two step molding approach where the ICs are first encapsulated in separate molded bodies that are similar to dual-in-line packages (DIPs) in outline and lead count. In this paper, these molded bodies will be referred to as DIPs -- although it is clear that they are not conventional DIPs. The molded IC DIPs can then be trimmed (the dam bars are excised) to allow IC testing. OSAs are then attached to the DIPs by resistance welding. Finally, the OSAs and DIPs are overmolded to form the ODL body. A final trim and form operation bends the leads and singulates the packages. This optical DIP (ODIP) is then placed in an injection molded shell as shown in figure 1.

PACKAGE DESIGN

Leadframe Design

A custom leadframe design was required. The design incorporates the two DIPs whose center axes are separated by a nominal 17.78 mm spacing of the OSA barrels. The leads fan out to the sides and the center is reserved as a means of connecting the EMI shield. Another unique feature of the leadframe is the accommodation of the OSA registration sites or saddles (as described below). Finally, several areas of the leadframe were designed for the attachment of small, surface mount capacitors (used for bypass and decoupling of the receiver). Although not common, attachment of discrete devices such as these have appeared in conventional and high performance IC packages. Fairly wide front and back rails were used to provide rigidity to the leadframe. The leadframe configuration consisted of four ODL sites (8 DIPs) per leadframe strip.

DIP Package Design

In addition to IC testing, the two DIP packages formed in the first molding step protect the integrated circuits from damage during the first trim & form operation and the OSA attachment. The DIPs are ostensibly the outline of 22 pin through-hole packages, but only 11 pins are used and they are along the outer edges, away from the interior of the ODL. Each DIP is 3.81 mm thick with leads protruding on 2.54 mm centers. The DIPs do not have any cosmetic requirements since they are encapsulated in the second molding operation. There were, however, several important aspects to their design. The outer surface should be as coarse as possible to promote adhesion between the first and second molding operation, but not so coarse as to inhibit easy ejection. The receiver (Rx) DIP, shown in figure 3, also has several blades of molding compound on the top surface that would act as spacers for the EMI shield that would be formed above it. With the spacers, a flow path under the shield is assured, hence mold filling problems are avoided. There are two ejector pin locations on each DIP, indicating that they are molded in an inverted position.

OSA Saddle Design

A unique feature of this design is the use of molded registration sites to hold the OSAs in place during attachment to the DIP, thereby preserving leadframe assembly without adding a special fixture. These sites, or saddles, are molded onto the leadframe during the first molding operation. The saddle consists of a semi-circular formation of molding compound approximately 2.54 mm thick. When molded, the saddle should make a close fit to the barrel of the OSA. This feature is filled with molding compound that flows from its corresponding DIP through secondary runners. Since the volume of material in the saddle is small, there is still sufficient pressure to fill and pack the saddles adequately. A close-up view of this runner and gate arrangement is shown in figure 4.

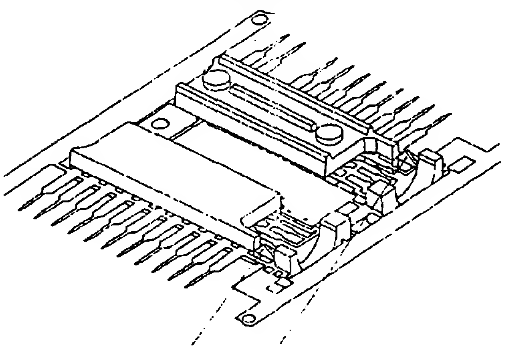

Figure 4. First molded package encapsulates ICs and forms OSA saddles

Overmolded Molded Body (ODIP) Design

The overmolded body or optical DIP (ODIP) must be large enough to capture both first molded DIPs (transmitter and receiver) as well as both optical sub-assemblies (OSAs). An illustration of this part is shown in figure 5. The outer surface of the second molding is also not an appearance part since it is largely covered by the outer shell. Design features include a notch in the back of the package where the receiver leadframe is attached to the baseplate. Five ejector pins are located on the bottom surface of the molded body. The ODIP is 10.16 mm thick to accommodate the large OSA barrels and to achieve the proper barrel to receptacle centerline

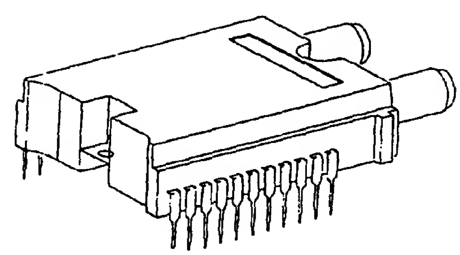

Figure 5. Formed and Singulated Optical DIP

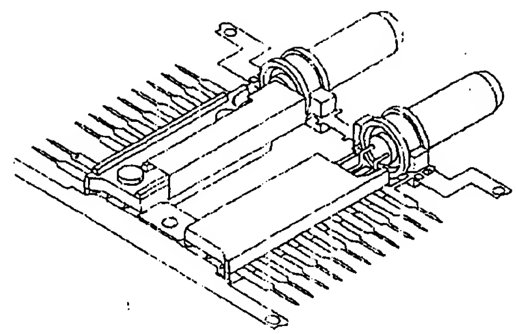

Figure 6. First molded package after OSA attachment & shield forming

Outer Shell/Receptacle Design

The final package will have a plastic outer shell that will serve the dual function of providing the package body as well as the Fiber Distributed Data Interface (FDDI) MIC connector receptacle. This is a tightly toleranced connector interface specified by ANSI. The shell is an injection molded part using poly (ether sulfone) (PES) material. Normally, the more traditional glass fillers are added to this plastic for improved material stability. However, to add enhanced shielding capability, this material can be loaded with carbon or steel fibers.

ASSEMBLY, MOLDING, TRIM & FORM

First Mold Leadframe Strip Assembly

Leadframe strip assembly begins by first epoxy bonding the bypass capacitors to the frame. The transmitter and receiver ICs can then be die bonded to the frames either simultaneously or consecutively. The ICs are then wire bonded to leadframe (simultaneously or consecutively). The leadframe strip is then placed in a transfer mold press. The initial mold used is a simple prototype mold with 8 DIP cavities (single strip). It is a conventional cavity mold with a trapezoidal main runner and sub-runners which feed the individual cavities. Gate sizes into the DIPs are 2.54 mm x 2 mm. The transfer press used was a 190 ton machine by C A. Laughton which was equipped with a process controller. Two molding compounds were evaluated -- Sumitomo 6300HD (86 cm spiral flow length) and Sumitomo 6300HD (118 cm spiral flow). Both compounds were used without issue. Mold temperatures of 170-175 C were used with a 90-95C preheat temperature. Transfer and hold pressures were at conventional levels and the transfer and hold profiles were largely flat. Flash and resin bleed were minimal on this molding. Post-cure was conducted after this molding operation, although an option would be to post-cure both the inner and outer moldings at the same time.

Lead Trim, OSA attachment and Shield Forming

The first trim & form operation prepares the DIPs for IC testing and subsequent OSA attachment. All dam bars between the leads are removed at this stage, electrically isolating the leads. In addition, the supports for the EMI shield are removed. The flat leadframe strip is then tested and the OSA "TO" leads are attached via resistance welding. Finally, a separate tool forms the shield over the receiver. An illustration of a single site of the completed assembly is shown in figure 6.

Overmolding and Final Trim & Form

The assembled leadframe strip is placed in the second transfer mold. Again Sumitomo 6300HD molding compound is used to form the ODIP body. Standard molding parameters were used in prototype fabrication. A photograph of the overmolded strip is shown in figure 7. A photograph of the singulated ODIP is shown in figure 8.

The second molding operation has to be performed on a leadframe where the dam bars between the leads have already been excised to facilitate the testing of the ICs. Although molding without dam bars is unconventional, it is not uncommon. It is becoming more popular with high lead count, fine pitch PQFPs and TSOPs where the thin, closely spaced leads make dam bar removal too difficult. In the absence of dam bars, most tools use what is known as "hibbles". These are small raised areas of the molding tool that fill in the area where the dam bar would be located, effectively blocking the flow of the molding compound between the leads.

In addition to lead flashing, there was also a concern of flash around the optical ports (barrels). The tool was designed with a radius that was only 0.005 mm larger than the diameter of the barrel, thereby affording a close fit without any coining. Subsequent trials indicated that there was little to no flash at this interface.

Figure 7. Photograph of Overmolded Leadframe Strip

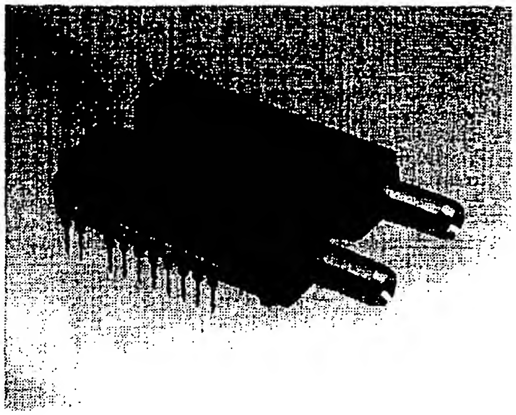

Figure 8. Photograph of Formed and Singulated ODIP

Final Assembly

The completed ODIP is then attached to a metal baseplate with epoxy and a single, self-taping #1 screw. Note that the screw connects the receiver leadframe to the baseplate. This connection is necessary to provide additional grounding and shielding for the high gain receiver. The ODIP/baseplate assembly is then inserted into the injection molded outer shell/receptacle. Features within the shell self-align the ODIP to the FDDI receptacle. The assembly is then secured using three self-taping, plastite screws as illustrated in figure 9. The resulting package is shown in figure 1.

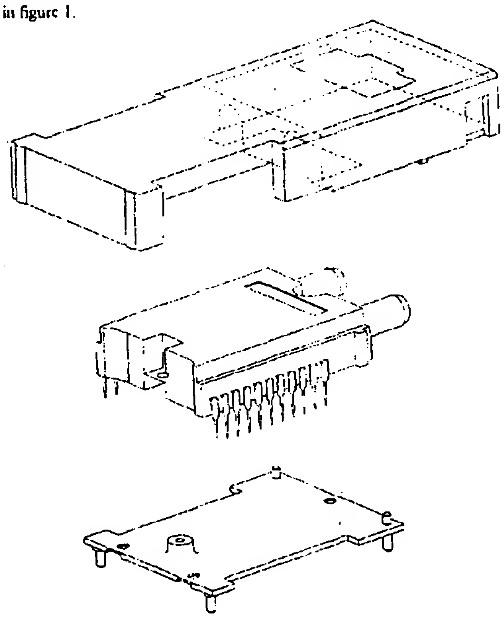

Figure 9. Final Assembly of Low Cost FDDI Transceiver Package

Additional Design Issues

Initially, a significant percentage of capacitors became detached during molding/trim & form. We found that the conductive epoxy joint between the capacitor termination and the leadframe was failing. It was initially thought that flow induced force of the molding compound was causing the problem. To resolve this issue, experiments were conducted to determine the push off force of the capacitor at various temperatures including the molding temperature

Table 1. Push-off force of epoxy bonded capacitor as a function of temperature.

Temperature (C)	Average Force (lb.)	Std. Deviation
25	7.95	2.67
150	1.42	0.46
160	1.22	0.48
170	1.12	0.31
180	0.76	0.25

Although these forces (Table 1) are well above those expected from the flow induced stress, calculations of the predicted viscous drag force and the unbalanced pressure force were performed to determine the amount of margin. The drag force calculation was based on the relations:

$$F_D = \frac{1}{2} C_D \rho U^2 A_w \qquad (1)$$

Drag Coefficient
$$C_D = \frac{8\pi}{Re(2.002 - \ln Re)} \qquad (2)$$

Reynolds Number
$$Re = \frac{\rho U L}{\eta} \qquad (3)$$

In these relations, the viscosity η = 30 gm/cm-sec (300 poise), the density ρ = 1.9 gm/cm^3, the Reynolds number is 0.016, the velocity U = 0.5 cm/sec and the wetted area A_w = 0.87 cm^2. This provides a viscous drag force of approximately 1×10^{-5} lb, far below the capacitor push-off force at the molding temperature (175 C). The pressure force is computed from the pressure imbalance that exists when the flow front is only partially across the capacitor length, effectively pushing it forward with the moving front. This force can be computed from the pressure drop encountered in the flow of Non-newtonian fluids [5] which has been applied to molding compounds in packaging applications by Manzione [3].

$$\Delta P = \frac{2KLQ^n A_s L}{W^n B^{2n+1} S p^n} \qquad (4)$$

This pressure force was computed to be of the order of .002 lb, greater than the viscous drag force, but still much less than force required to push the capacitor from the bonding site.

It was then theorized that the capacitor connection was severed due to excessive drag force while trimming the external leads. The leadframe design was changed to move the capacitor away from the package edge. In addition, locking features were added to the lead to reduce internal leadframe stress. Subsequent models verified that these changes corrected the problem.

An additional area of concern was initial excessive flashing along the package leads. Occaisonaly, small gaps between the hibbles and the leads can cause this problem. In this case, however, we determined that an oversized leadframe was preventing the mold from completely closing. While some leadframe coining does occur, incomplete mold closing allows flash to occur over the hibble and down the lead. A simple tooling change corrected this problem.

Electrical Performance

Fifty prototype models were assembled as a preliminary check on optical data link performance. Initial units did not meet FDDI requirements but were fully functional and useful for package integrity testing. These units were characterized (over temperature and supply voltage) and then put through a full round of initial qualification testing. Devices easily passed initial qualification testing.

Subsequent changes to the receiver circuit design yielded significantly improved performance – easily meeting FDDI requirements. A comparison of the resulting performance with the current generation transceiver is summarized in Table II.

Table II. FDDI Transceiver Performance Comparison

		Typical Results		
Parameter	FDDI PMD	AT&T 1402U	Overmolded Transceiver	Units
Transmitter:				
Rise Time	3.5 max	1.0	1.2	ns
Fall Time	3.5 max	1.9	1.8	ns
Avg. Opt. Pwr.	-20/-14	-16.3	-16.0	dBm
Duty Cycle Dist.	0.6 max	0.10	0.15	ns p-p
Receiver:				
Saturation Pwr.	-14.0 min	-12.0	-12.0	dBm
Sensitivity *	-32.2 min	-37.2	-37.9	dBm
DCD	0.4 max	0.10	0.15	ns p-p

* @ 1×10^{-6} BER, zero eye, 2^7-1 PRW, 125 MB/s

Conclusions

A molded plastic packaging technology for optical data link transceivers has been developed and demonstrated in prototype form. We successfully integrated several high speed electrical and optical components into a single, sealed, overmolded package. We have demonstrated the feasibility of manufacturing optical data links using traditional IC packaging concepts. The assembly and molding was thoroughly tested in an extended prototype period where several important tooling modifications were made. With subsequent circuit changes, final design units easily met FDDI specifications.

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